Chasing the Holy Grail: Successful Academic Persistence and Retention of Highly Motivated First-Year Engineering Students

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Abstract

The 2012 ASEE report "*Going the Distance*" outlined efforts of exemplary engineering institutions to promote undergraduate engineering retention, with particular emphasis on student-level support and interventions like tutoring, advising and co-curricular activities. This paper outlines efforts at a rapidly growing college of engineering to reduce attrition by 10% by better understanding 1st year students cognitive and non-cognitive profiles, testing an applied engineering math course, and incrementally shifting faculty and administrative culture from transactional relationships to higher quality student engagement for 1st year students. Between Fall 2014 and Fall 2015 qualitative data was collected measuring new students' initial "grit", motivations and career expectations. The total sample (N=509) consisted of 84% freshmen, 16% transfers, 21% women and 14% minority students. Quantitative data included an analysis of the high school SATs and initial university math placement scores for Fall 2014-Fall 2015, a comparative analysis of the same data for the Fall 2011-Fall 2013 cohorts, and an analysis of student outcomes from an adapted version of the Wright State University's EGR101 applied engineering math course, offered to students most at risk for failing math in the first year. This paper will outline the interventions, discuss the successful 10% drop in attrition across the two cohorts, and share progress shifting institutional culture to retain more highly motivated students beyond the first year.

Context & Background

Temple University's College of Engineering is one of seventeen colleges within a large, urban public university system, and is recognized as one of the fastest growing, most diverse and most successful relative to student post graduation success. However, like most engineering institutions, the college has struggled with the traditional attrition associated with academically difficult programs, particularly those in the sciences, technology, engineering and math (STEM) domains. The inadequate retention and graduation of the college's engineering students mirrors the national struggle of engineering institutions to reduce attrition.

While the demand for engineering education has quadrupled the size of the college in one decade, the estimated cumulative attrition rates are very high, such that for every 100 students who start, 75% are retained after the first year, and 45% after the second year. In total, due to a variety of reasons including financial burden, only 18% were obtaining baccalaureate degrees in four years. In comparison, the freshman retention rate across the university is approximately 89%, and on-time (e.g. four year) graduation rates average nearly 67% depending on the program

Fueled by national calls to produce more diverse, highly qualified domestic engineering talent, the college is also grappling with the challenge of new university policies to decrease student debt load by graduating more undergraduates in four years, and the operational realities of a university-wide admissions policy yielding a disproportionate number of mathematically underprepared students entering engineering in the first year. Against this backdrop of compelling strategic priorities, this working paper outlines a series of data driven-decisions to reduce attrition in the first two years of matriculation, and ideally double student graduation rates by 2018.

Although it is well understood that financial aid and academic supports are a large part of the retention equation, this study examines the impact of exposure to engineering math as a cognitive support on two successive years of freshmen that matriculated in Fall 2014 and Fall 2015. This paper suggests that math remediation is critical, but must be done in an institutional context that successfully leverages student determination to succeed.

The traditional faculty-led argument that "we are admitting poorly prepared students" could no longer serve as an explanatory factor, as the university's undergraduate program admissions had become increasingly competitive, and were generally more productive yielding graduates. In the College of Engineering, SAT scores had continued to rise and most first year engineering students were presenting SAT scores well above the national average, across gender and ethnicities. In addition, the college used validated instruments to assess psychological predisposition, which revealed that 95% of the 1st year students in this study consider themselves to be "gritty" and 86% reported very strong self-efficacy (belief) in their ability and high school math preparation to study engineering.

However, in contradiction to their above average SAT scores, half of the first year students entering Temple Engineering in Fall 2014 and Fall 2015 tested below Calculus I, only 33% had experienced a high school engineering course or activity, less than 33% had a family member in a STEM field, and only 5% had ever had an industry mentor.

As a result, the College elected to address its operating culture and context to better support determined, high potential first year students, leveraging both cognitive and non-cognitive strategies given the disproportionate number of mathematically underprepared students. The decision provided the opportunity to test complementary strategies this paper will present. It is hoped that the results will benefit other engineering colleges seeking to improve student outcomes using evidence-based measures.

Methodology

Engineering educators benefit from understanding psychological theories that help explain students' motivation to persist. Recent theories like Social Cognitive Career Theory (Lent, Brown & Hackett, 1994; 2000) facilitate deeper analysis of relationships between an individual's confidence and goal orientation, and the contextual choices they make to achieve a specific career (2000). Complementary theories like "grit", defined as "perseverance and passion for long-term goals" (Duckworth, et al 2007), and self-determination theory (Deci & Ryan, 2000) also provide plausible frameworks for evaluating data on 1st year engineering students' responses to interventions designed to reduce attrition by 10% in the first year of admission to a large, public university's college of engineering.

Prior to selecting retention strategies a retrospective analysis was completed for first-year engineering students who had entered the college in 2011, 2012 and 2013 (N=1,484). The descriptive analysis yielded data on gender (84.8% male, 15.2% female), race/ethnicity (38.9% white, 11.9% Black, 7.2% Asian, and 2.5% Hispanic with 34% not reporting), and an above average SAT Math mean of 566 – the national average was 512 for that period.

Regression analysis for the same period compared high school SAT Math scores with university math placement scores by student type (freshman versus transfer) and yielded no discernible differences on math placement scores, SAT Math scores and GPA in placement course based on gender. However, among ethnic groups African American students had the lowest SAT scores of the identifiable ethnic groups, although still above national standards (M=542 vs. M=512).

In the following chart, SAT Math scores correlated to student math placements (regardless of ethnicity) yielding the following results for three possible starting points in the engineering degree program:

- Entry-level college math (MATH 0701, MATH 0702 and MATH 1015)
- Pre-Calculus (MATH 1021, MATH 1022, and MATH 1031)
- Calculus I (MATH 1041)

In the chart below, initial math placement is correlated to the average SATs of students placed in that course. Using math placement as a predictor of time to completion, students who placed into any course before Calculus (MATH 1041) entered one to two semesters behind and most likely to face a five-six year graduation timeline.

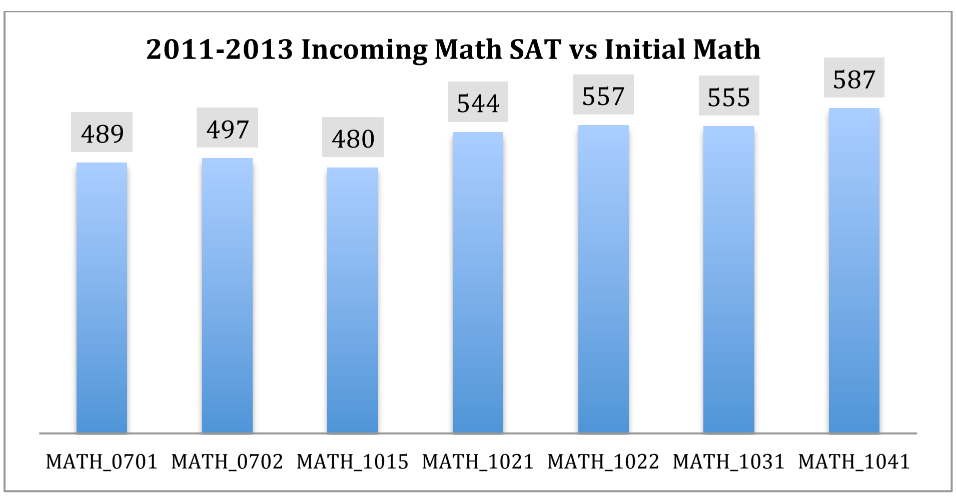

Chart 1: Incoming 1st Year Engineering SATs versus Initial Assigned Math Course (2011-2013)

Using the 2011-2013 data as comparative baselines, a descriptive and regression analysis for Fall 2014 and Fall 2015 revealed continued and significant deficiencies in actual math readiness - 60% of the incoming 2014 cohort and 42% of the incoming 2015 cohort placed below Calculus I. (Most transfer students had already completed at least 2 courses in the calculus sequence and are not included in this analysis.) Regression analysis of the university's math placement scores found only modest correlation with SAT (r=.564-Part2; r=511-Part3), but absent an alternative the SAT was still used as an equating proxy of 1st year students' math skills.

Because data from the 2011-2013 cohort could not explain the attrition of 1st semester students with above average math SATs, or the persistence of students who had entered with below average SATs, the college created its first retention committee in 2014 to identify interventions to help more students experience success in the first two years. The retention committee, launched in Spring 2014, identified three retention strategies:

- math intervention (including course modification and supplemental instruction),
- improved faculty engagement to support retention, and
- building the capacity of student engineering organizations to support retention among their peers.

The established goal was to reduce attrition by 10% (from 25% in year 1 to 20%), and in year 2 to increase retention from 45% to 50% across the 2014-2015 cohorts. Math remediation was prioritized and the college modified and piloted the NSF funded Wright State EGR101 engineering math course. The course was introduced as a section of the existing 1st year *Introduction to Engineering* course.

The new course was listed as ENGR1102/1103 the course was led by the Dean, team taught by faculty from four disciplines, included discipline specific labs, supplemental instruction via online digital archives, provided weekly recitations and eliminated MATLAB. The Wright State model used a single instructor, provided general engineering labs and both MATLAB and recitations were required.

A carefully worded email was sent from the Dean to at risk students who tested into the bottom quartile on the math placement test. New students were identified as "early engineers" and encouraged to take ENGR1102/1103 to improve their math skills and increase their likelihood of earning the degree. The course was piloted for three consecutive semesters with the following demographics:

Descriptive Statistics	**Fall 2014 (N=46) ENG 1102**	**Spring 2015 (N=14) ENG 1102**	**Fall 2015 (N=27) ENG 1103**
Males	84%	84%	79%
Females	16%	16%	21%
Freshman	98%	0%	93%
Transfer	2%	100%	7%

White	68%	42%	50%
African-Am	14%	50%	25%
Asian	11%	8%	11%
Hispanic-Latino	7%	-	4%
Native Am/PI	-	-	-
Initial Math Course:			
Calculus I	22%	25%	22%
Pre-Calculus	37%	58%	64%
College Algebra or below	31%	17%	14%

Table 1. Demographic profile of students enrolled in engineering math remediation course by semester.

The results of the math remediation across each semester were very encouraging. At risk students who tested into entry-level math courses (algebra to pre-calculus), and took the ENGR1102/1103 course *concurrent* with their math class, achieved a statistically significant improvement between pre- and post-test, with an effect size considered large (t=2.56, $\eta_{\wp}^{2} = .138$). Their improved performance in math *after* taking ENG1102/1103 (t=.342*, p=.079) is close to being statistically significant (p<.05).

Students who took ENGR1102 averaged a 96% pass rate across the cohort (N=38). Overall the impact of offering math remediation within the college of engineering has been successful, :

Cohort	# Enrolled	Attrition Goal YR 1	**Actual Attrition**	Retention Goal YR 2	**Actual Retention***
Fall 2014	46	<25%	**<20%**	>45%	**>70%**
Fall 2015	27	<25%	**<15%**	--	**>85%**

Table 2: Projected vs actual attrition and retention for 2014-2015 for students enrolled in ENGR1102. *As of Spring 2016.

Certainly math remediation offered within the college of engineering improved student outcomes and retention, with a disproportionate benefit to underprepared first year engineering students. However, knowing *what* happened does not explain *why* at risk first year engineering students persisted. To that end, additional qualitative data was gathered to develop a broader profile of the students entering engineering – including their motivations, self-confidence and goal orientation toward achieving a coveted degree.

Non-cognitive Factors: Engineering Personality Traits

Understanding the intersection between first year students' self-confidence, goals, persistence and their academic preparation can help efforts to improve engineering retention. The interventions outlined in this paper were guided by Social Cognitive Career Theory (SCCT) (Lent, Brown, & Hackett 1994; 2000), which identifies *self-efficacy* (confidence based on past performance and personal accomplishments), *outcome expectation* (belief that hard work will be rewarded) and *personal goals* (level of determination and drive to achieve a specific goal) as core to achievement orientation.

SCCT provided a framework for exploring student characteristics beyond academic performance. It is argued that absent a strong sense of self-efficacy and outcome expectations, the students in ENGR1102 would traditionally have been pushed out of the degree. Instead they persevered and this study offers analysis on the traits that contributed to their decision to stay. To that end, incoming students in Fall 2014 and Fall 2015 were asked to complete a 12-item "grit" survey the first week of class (Duckworth, et al, 2007, p.1087-1101).

Duckworth and colleagues (2007) define **grit** as "perseverance and passion for long-term goals. Grit entails working strenuously toward challenges, maintaining effort and interest over years despite failure, adversity, and plateaus in progress" (p. 1087-1088). A key assumption is that pursuing an engineering degree requires significant persistence and grit. In addition to grit, **self-discipline** is of interest. Low STEM achievement in U.S. schools is often blamed on teachers, standards, and curriculum. Duckworth and Seligman (2005) suggest that the reason students do not perform to their intellectual potential is their "failure to exercise self-discipline" (p.944). In other words self-discipline has a greater impact on academic performance and long term success than raw intellectual talent.

Self-discipline was also found to be more critically important to long-term success on every measure of academic achievement than IQ (Duckworth & Seligman, 2005). In 2013, the U.S. Department of Education released a report entitled "Promoting Grit, Tenacity, and Perseverance: Critical factors for success in the 21st century." However, only a few relatively small studies have begun to look at non-cognitive traits like grit and self-discipline in STEM fields specifically (e.g. Gibbs & Griffin, 2013).

The grit survey used a bi-directional five-point scale such that items 1, 4, 6, 9, 10 and 12 were rated with decreasing intensity from *5=very much like me* to *1=not like me at all*, while items 2, 3, 5, 7, 8 and 11 were rated with increasing intensity from *1=very much like me* to *5=not like me at all.*

GRIT & PERSEVERENCE ITEMS	Fall 2014 N=280	Std Dev, σ	Fall 2015 N=229	Std Dev, σ
I have overcome setbacks to conquer an important challenge	3.97	0.26	4.05	0.31
New ideas and projects sometimes distract me from previous ones	3.08	0.31	3.02	0.31
My interests change from year to year	3.47	0.35	3.39	0.4
Setbacks don't discourage me	3.73	1.4	3.52	0.31
I was obsessed with a certain idea or project for a short time but lost interest	3.46	0.53	3.37	0.56
I am a hard worker	4.37	1.78	4.37	0.81

I often set a goal but later choose to pursue a different one	3.61	0.24	3.56	0.26
I have diffculty maintaining focus on projects that take more than a few months to complete	3.62	0.48	3.62	0.51
I finish whatever I begin	4	0.14	4.05	0.11
I have completed a goal that took years of work	3.71	1.88	3.71	0.05
I become interested in new pursuits every few months	2.86	0.94	2.82	0.97
I am diligent	4.19	2.66	4.2	0.4
Overall "Grit" Profile by Cohort	**3.68**	**0.43**	**3.64**	**0.47**

Table 3: 2014 and 2015 1st Year Engineering "grit" profiles.

The nearly identical results for two separate cohorts suggested that similar student personality types were admitted to the college of engineering with above average "grit" or passion to succeed against obstacles (2014 – 3.68, SD 0.43; 2015 – 3.64, SD 0.47).

The next section examines student on motivation to become engineers, a broader context than the focus on academic support for the most at risk students. Their motivational profiles offer a richer, more contextualized understanding of the entire cohort, and a better understanding of approaches to retention that affect the entire cohort, of which at risk students were one small part.

Engineering Student Motivational Baselines

While both Fall 2014 and Fall 2015 cohorts entered college with above average levels of grit, nearly two thirds had no access to pre-college engineering opportunities to help make an informed decision about pursuing an engineering career. Turning again to Social Cognitive Career Theory to assess the context of the college, it became clear that a cultural shift to support retention would first need to engage highly motivated students 1st year students in understanding engineering in the context of professional rigor. Thus the selection of the Wright State EGR101 model was timely and effective; it blended exposure to math in the context of the domain, and provided an opportunity to accelerate what students knew about the career while improving academic performance.

Stated differently, whatever motivated students, it wasn't actual knowledge about the career. In Chart 2 below, two thirds of students had not participated in pre-college engineering activities, courses or clubs.

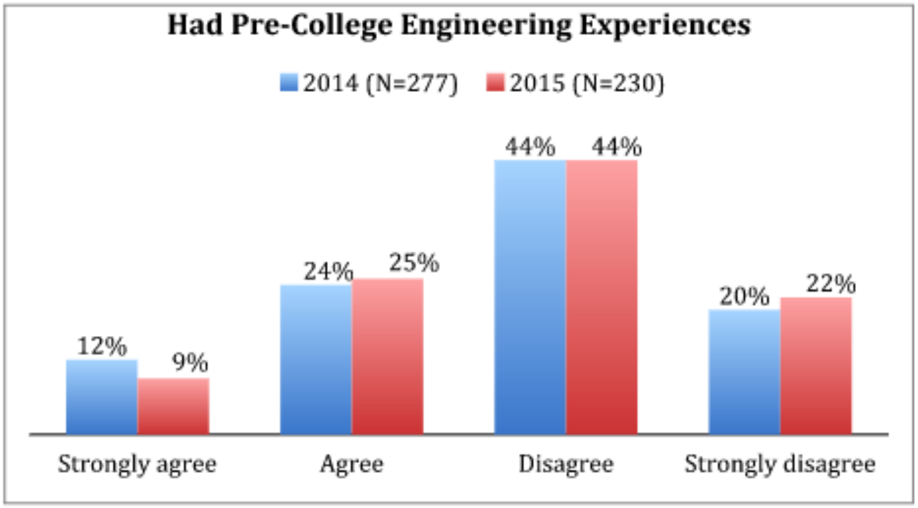

Chart 2: 1st Year students' pre-college engineering exposure.

In addition, 1st year engineering students expressed significantly higher *intrinsic motivation* to design, build and improve things than *extrinsic motivation* to make money or gain social recognition. The responses suggest these 1st year students believed pursuing a career that aligned with their passion was satisfaction enough. Again, it is important to note these responses are consistent across gender, ethnicity, and socio-economic status.

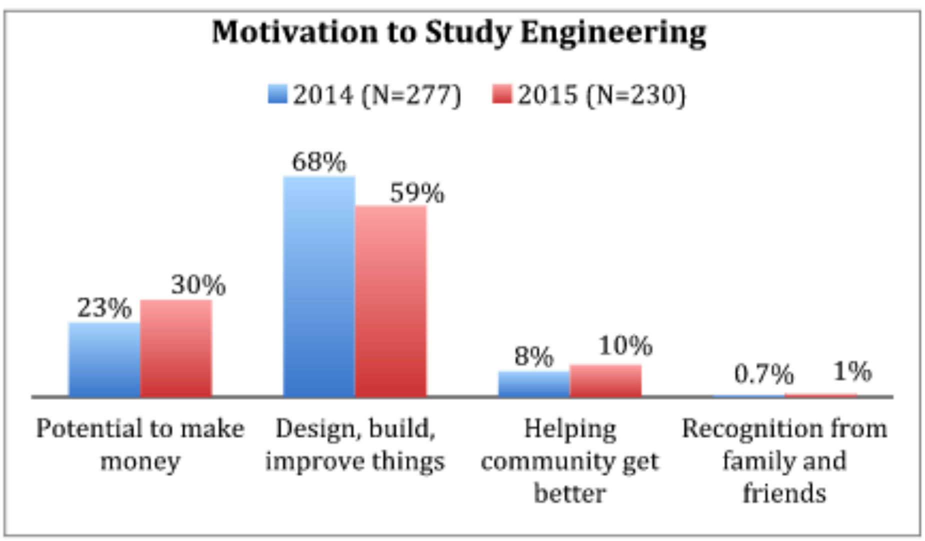

Chart 3: Motivation of 1st year engineering students with limited pre-college experience.

Finally, both SCCT and grit theories are helpful for interpreting that students elected engineering based on their past performance and belief they were sufficiently prepared in high school math and science courses to pursue a career that was not only valued by them, but they had the fortitude to pursue. For those 1st year students who may have been high achievers in high school, but performed poorly on the college math placement test, the strong self-efficacy and determination clearly supported their individual drive to move to the next level in the degree.

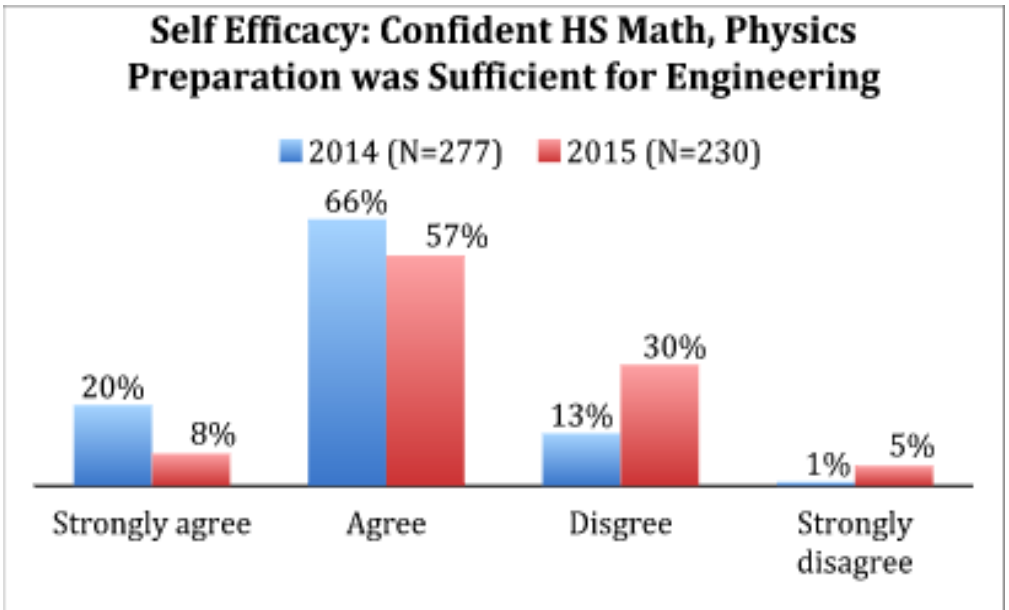

Chart 4. Entering 1st Year student confidence in high school STEM preparation.

In the context of the university's generalized rather than differential admission policy, students who elected to matriculate in engineering without sufficient preparation were less likely to know the implications of failed courses, increased debt load and negative GPA outcomes on their progression in a very rigidly structured degree program. The engineering retention committee recommended development of full program of student support, including adoption of best practices identified by ASEE: peer tutoring, advising, and mentoring. Additional efforts have been made to engage the college faculty and staff in developing a summer residential "Intro to Engineering" bridge to provide information on the nature and context of engineering programs of study to help parents and students to make the best decision before committing precious resources.

The case can be made that engineering students may be willing and able to persist in engineering if they are better prepared through the first few courses to understand the full requirements to graduate. For students who enter underprepared, emerging evidence from this study suggests those students who desire the engineering degree and have the fortitude to persist may do so, in spite of initial academic deficiencies, as long as they understand it may take longer or be harder than they initially thought.

Impact of Secondary Interventions

The success of ENGR1102/1103 in remediating mathematically at risk first year students was the catalyst for two supplemental interventions that emerged as the culture of the college shifted to retain "early engineers" in the Fall 2014 and Fall 2015 cohorts. Emerging research on institutional context suggests that in addition to considering student level interventions (micro-level), there are meso- and macro-level influences operating within the college and university that can influence or derail engineering graduation (Hughes, et al, 2013). One of the most important macro-level influences was the power of key faculty influencers to serve as early adopters and champions of retention strategies.

In an effort to promote faculty buy-in and support (and constructively challenge the long held belief that pre-college math preparation was the ultimate predictor of success), a body of evidence to support was presented during a summer 2014 faculty retreat in advance of piloting the math intervention in fall 2014. The Dean presented the retrospective data from 2011-2013, the incoming math deficiencies for students matriculating in Fall 2014 and updates to university policy regarding "Fly in Four" goals for thousands of first year students throughout the university. In spite of the data showing the disconnect between higher SATs and university math placement tests, initial response was to view the data with some skepticism and to demand admission of "better qualified" students. However, when presented with the preliminary outcome data in summer 2015, and the projected impact on revenue, proactive faculty support emerged.

For example, two senior faculty members took the initiative to form ad hoc committees to support retention. The first created a listserv with articles, blogs and opinions about engineering retention and distributed monthly to all faculty to energize discussion. That faculty member also volunteered help develop an online introduction to engineering module for incoming 1st year students. The second faculty member's committee reviewed annual student feedback data and initiated an ethnographic study in Spring 2016 to help struggling peers implement more engaging instruction for themselves and their students. A third used sabbatical to develop an upper class version of ENGR1102/1103 for teaching differential equations.

These are compelling examples of a shift in culture from passive to active engagement in student retention. The college leadership team is activity supporting each activity. In addition, the college is developing formal relationships with student chapters of professional engineering organizations (SPOs). These organizations have been at the cornerstone of informal retention efforts, providing tutoring support, class advising and professional networking activities outside the context of the college. Going forward fourteen (14) engineering SPOs will receive an orientation to operating within the college, capacity building support and an annual budget for operations in recognition of their importance providing peer tutoring and peer advising to new and transfer students within the Office of Undergraduate Affairs.

Conclusion

This study demonstrated a 5% decrease in attrition and 25% improvement in retention for at risk first year students entering a college of engineering in Fall 2014, and a 10% decrease in attrition and nearly 35% increase in retention for a similar cohort of mathematically underprepared student entering Fall 2015. The success mediating academic deficiencies by offering math interventions and indirectly changing the culture of the college to better engage faculty and students has retained students who likely would have failed to progress in the degree without support.

Equally important, the culture of the College has shifted, improving the context for all key stakeholders, particularly students. There is stronger engagement of faculty, administrators and staff to support retention. The original *Introduction to Engineering* course is being redesigned to expose 1st year students to industry mentors who can showcase the innovation embedded in engineering careers. Finally, the college is exploring opportunities to offer ENGR1102/1103 to all incoming 1st year engineering students, will implement both online and campus based bridge programs and recognize faculty who champion retention within their departments.

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